

# X-rays from Radio-Galaxies: BeppoSAX Observations

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We briefly review BeppoSAX observations of X-ray bright radio-galaxies. Their X-ray spectra are quite varied, and perhaps surprisingly, any similarity between radio-loud AGN and Seyfert galaxies is the exception rather than the rule. When detected, reprocessing features (iron line and reflection) are generally weak, suggesting two possible scenarios: either: (1) non-thermal (jet?) radiation dilutes the X-ray emission from the disk in radio-loud objects, or (2) the solid angle subtended by the X-ray reprocessing material is smaller in radio-loud than in radio-quiet AGN due to different characteristics of the accretion disk itself.

## 1 Introduction

X-ray observations of radio-galaxies can play an important role in understanding the AGN radio-loud and radio-quiet dichotomy. Several authors have speculated upon the possibility that the AGN distinction in two big families reflects different physical properties of the nuclear engine. Several years ago, Rees et al. (1982), suggested that in the nuclei of radio-galaxies a spinning black hole is surrounded by a hot thick accretion flow, in contrast with the radio-quiet picture, which assumes the accreting material in shape of cold thin disk. Later, other authors (Blandford 1990, Meier these proceedings) indicated the black hole spin as the physical parameter responsible of the AGN dichotomy, being more rapid in radio-louds and therefore more efficient in producing powerful jets.

X-ray photons are produced in the inner regions ( $< 1$  pc) of AGN and provide crucial information on physical processes occurring very near to the black hole. X-ray studies of radio-galaxies are then essential to answer a fundamental

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Table 1

Source	z	Optical Type	Radio <sup>a</sup> Morphology	$L_{2-10\text{keV}}^b$ erg cm <sup>-2</sup> sec <sup>-1</sup> )
PKS2152-69	0.027	BLRG	FRI/FRII	$0.2 \times 10^{44}$
Pictor A	0.035	BLRG	FRII	$1.0 \times 10^{44}$
3C120	0.033	BLRG	FRI/S	$2.4 \times 10^{44}$
3C111	0.048	BLRG	FRII/S	$2.9 \times 10^{44}$
3C390.3	0.057	BLRG	FRII/S	$3.3 \times 10^{44}$
3C382	0.059	BLRG	FRII	$9.4 \times 10^{44}$
Cen A	0.002	NLRG	FRI	$0.5 \times 10^{43}$

<sup>a</sup> – S = superluminal source; <sup>b</sup> – Luminosity corrected for absorption

question: are the same accretion processes at work in radio-loud and radio-quiet AGNs?

In this paper, we present an on-going analysis of radio-galaxies observations performed with the BeppoSAX satellite (0.1-150 keV) and discuss the results of a comparative study between our sources and a sample of 12 Seyfert galaxies (Matt 1999) observed with the same satellite.

## 2 Results

Our sample (Table 1) consists of 6 Broad Line Radio Galaxies (BLRG), the radio-loud counterpart of Seyferts 1 in the AGN Unified Schemes. Most of the sources have a Fanaroff-Riley (FR) II radio morphology and 3 shows superluminal motions. For comparison, one Narrow Line Radio Galaxy (NLRG), Centaurus A (Cen A), is also included in the sample. As two observations are available for this source, a spectral variability study was also possible.

The X-ray spectra of radio-galaxies are complex (Fig. 1) and varied, as shown in Table 2 where the spectral fit results are listed. A simple power law plus Galactic absorption generally did not give good fits to the data. We then tested a more complex model which takes into account all the spectral components usually observed in Seyfert 1 galaxies: a power law which an exponential cutoff (Cutoff), a fluorescence  $K_\alpha$  iron line and a reflection component (Refl). The theoretical picture which interprets the Seyfert spectra assumes a cold thin optically thick disk with a hot corona above it. The corona produces the X-

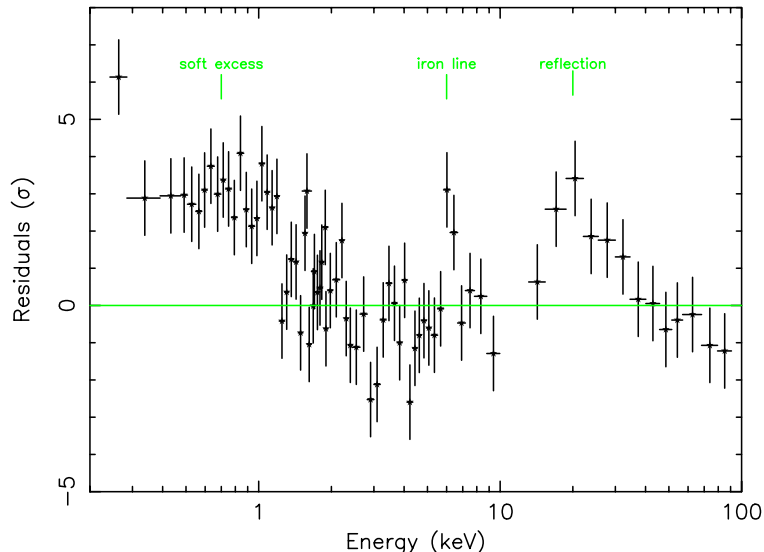


Fig. 1. The complex spectrum of 3C382. When the BeppoSAX data are fitted with a simple power law, residuals show an excess of emission at soft energies, an iron line at  $\sim 6.4$  keV and a reflection hump above 10 keV

ray photons by inverse Compton of the UV disk radiation. The disk itself reprocesses the down-scattered X-ray radiation producing the iron line and a hump above  $\sim 10$  keV (Haardt and Maraschi 1991, Haardt and Maraschi 1993).

A multicomponent spectrum is generally a good representation of the data, although all the spectral features were not always simultaneously present in each source. In some cases, it was also necessary to include a soft excess (parameterized with a steep power law  $\Gamma_{soft} = 2 - 3$ ) and/or to include an extra absorption in addition to the Galactic one (see Table 2).

*Continuum of emission* – The shape of the BLRG primary X-ray continuum does not significantly differ from that of Seyfert 1 galaxies (Matt 1999). The BLRG spectral slopes and the cutoff energies (when detected) are consistent with those observed in Seyferts 1 ( $< \Gamma^{Sey} = 1.85 >$ ,  $\sigma_{rms}^{\Gamma} = 0.22$ ;  $< E_{cutoff}^{Sey} = 237 >$  keV,  $\sigma_{rms}^{cutoff} = 150$ ).

*Soft excess* – Soft excesses were found in 3C120 and 3C382. Since these are the AGNs in our sample with strong UV bumps (Maraschi et al. 1991, Tadhunter et al. 1986), we suggest that the soft photons represent the hard tail of the thermal emission associated with the accretion disk.

*Cold Absorber* – A cold absorbing column in excess of Galactic is observed not only in the NLRG Centaurus A, but also in half the BRLGs of the sample. In contrast, we did not find any signatures of warm absorber which is rather common in Seyferts (Matt 1999). This result suggests that the nuclear

Table 2

Source	$\Gamma$	$N_H$ ( $10^{21} \text{ cm}^{-2}$ )	Refl.	Cutoff keV	$E_{Fe}$ keV	$\sigma$ keV	EW eV
PKS2152-69 <sup>c</sup>	1.79±0.1	0.25 (f)	...	...	6.4 (f)	0.0 (f)	< 429
Pictor A	1.63±0.06	0.42 (f)	...	...	6.4 (f)	0 (f)	< 102
3C120*	1.80 <sup>+0.12</sup> <sub>-0.30</sub>	2.4 <sup>+1.8</sup> <sub>-1.3</sub>	0.7±0.4	109 <sup>+125</sup> <sub>-77</sub>	6.2±0.4	0.27 <sup>+0.40</sup> <sub>-0.27</sub>	59 <sup>+82</sup> <sub>-42</sub>
3C111 <sup>†</sup>	1.65±0.04	7.1 <sup>+0.9</sup> <sub>-0.8</sub>	< 0.3	> 90	6.6 <sup>+0.4</sup> <sub>-0.2</sub>	0 (fixed)	58 <sup>+31</sup> <sub>-55</sub>
3C390.3	1.80 <sup>+0.05</sup> <sub>-0.04</sub>	1.3±0.2	1.2 <sup>+0.4</sup> <sub>-0.3</sub>	> 123	6.4±0.1	0.07 <sup>+0.21</sup> <sub>-0.07</sub>	136 <sup>+40</sup> <sub>-36</sub>
3C382*	1.79±0.04	0.88 (f)	0.4 <sup>+0.3</sup> <sub>-0.2</sub>	155 <sup>+148</sup> <sub>-59</sub>	6.5 <sup>+0.9</sup> <sub>-0.2</sub>	0.00 (f)	31 <sup>+44</sup> <sub>-15</sub>
Cen A(1997)	1.76 <sup>+0.04</sup> <sub>-0.06</sub>	98 <sup>+20</sup> <sub>-30</sub>	0.2±0.1	286 <sup>+257</sup> <sub>-94</sub>	6.48±0.07	0.3±0.01	166 <sup>+38</sup> <sub>-32</sub>
Cen A(1998)	1.73 <sup>+0.05</sup> <sub>-0.04</sub>	92 <sup>+30</sup> <sub>-10</sub>	0.1±0.1	297 <sup>+156</sup> <sub>-79</sub>	6.38±0.08	0.08 <sup>+0.26</sup> <sub>-0.08</sub>	57 ± 18

<sup>a</sup> – photons  $\text{cm}^{-2} \text{ sec}^{-1} \text{ keV}^{-1}$ ; <sup>b</sup> – ergs  $\text{cm}^{-2} \text{ sec}^{-1} \text{ \AA}^{-1}$ ; <sup>c</sup> – MECS data only

\* – Sources with detected soft excess; <sup>†</sup> – iron line marginal detection

environments of radio-loud and radio-quiet AGN might be different.

*Iron Line and Reflection Hump* – While in Seyfert 1 sample the iron line is always detected, in BLRGs the reprocessed feature is detected in half the sources. In addition, in BLRGs the iron line equivalent widths are significantly smaller than in Seyfert 1s ( $\langle EW^{BLRG} = 71 \rangle \text{ eV}$ ,  $\sigma_{rms}^{BLRG} = 45$ ;  $\langle EW^{Sey1} = 175 \rangle \text{ eV}$ ,  $\sigma_{rms}^{Sey1} = 52$ ). The weakness of the iron line in BLRGs indicates that a simple Seyfert-like picture is not suitable to describe the nuclear region of radio-galaxies.

All the BLRGs with detected iron lines show a reflection bump. Although the strength of the reflection is not very well constrained, there is indication that weak reflection corresponds to weak iron line (see Table 2). This is consistent with the Fe line arising in the same material that reflects (and reprocesses) the primary X-ray continuum.

*Iron Line Variability* – Iron line variability studies are extremely powerful to investigate the location of the emitting gas. In the BeppoSAX observations of Cen A (Table 2) the iron line was more intense when the source was weaker. The total number of photons in the line was about twice as large as in the first BeppoSAX observation when the nuclear flux of the source was 25% lower (see fig.1 in Grandi et al. 1998). **This lack of direct correlation shows that the iron line emitting region responds with a significant delay to the continuum variations and therefore cannot be located near the primary X-ray source.** A similar conclusion was reached by Wozniak et al.

(1998) for 3C390.3, for which ASCA and Ginga observations did not reveal any long term variability in the Fe line when the continuum flux changed.

The comparison of our data with previous observations by GINGA (Nandra and Pounds 1994) and ASCA (Grandi et al. 1997) shows that a similar lack of correlation between the continuum flux and the Fe equivalent is present also in 3C120 and 3C382. In both radio-galaxies, BeppoSAX measured a continuum flux higher than ASCA and GINGA, but significantly weaker Fe equivalent width. 3C120 and 3C382 have spectral characteristics of Seyfert 1s. Both have a huge UV bump and a soft excess probably produced by a cold accretion disk. In addition, ASCA detected a broad iron line in both these sources (Grandi et al. 1997, Reynolds 1997), as expected if produced in the inner region of the accretion flow.

**In this case, the observed dilution of the equivalent width could be produced by an increase of the jet intensity rather than by a delayed response of the cold matter to variations of the X-ray source.**

### 3 Discussion

BeppoSAX analysis of radio-galaxies has pointed out important differences between radio-loud and radio-quiet AGN and has clearly shown, for the first time, that in BLRGs the iron line equivalent widths (and probably the reflection strengths) are significantly smaller than in Seyferts 1.

In some radio-galaxies the cold material responsible for the line production is located far from the X-ray primary source. It is possible that the innermost part of the accretion flow is not in shape of cold disk. The accretion flow might be then hot and geometrically thick in the inner regions (Rees et al. 1982, Shapiro Lightman and Eardley 1976, Narayan et al. 1998) and cold optically thick (Shakura and Sunayaev 1973) only at larger radii, subtending relatively smaller solid angles (compared to Seyfert 1s). Featureless spectra or weak iron lines could be signatures of low efficiency accretion processes.

In sources with Seyfert-like spectra (i.e, with soft excess, strong UV bump and broad iron lines), the Fe line might be produced by a cold thin optically thick disk (Seyfert-like accretion flow). In this case, the iron line EW might be diluted by the Doppler-enhanced non-thermal jet continuum. This explanation predicts that the observed continuum (disk +jet) is more variable than the Fe line (disk).

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